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## **Antioxidants Properties and Effect of Processing Methods on Bioactive Compounds of Legumes**

Ma. del Socorro López-Cortez,  
Patricia Rosales-Martínez,  
Sofía Arellano-Cárdenas and  
Maribel Cornejo-Mazón

Additional information is available at the end of the chapter

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### **Abstract**

Extensive research has proven that fruits and vegetables contribute significantly to the body supply of bioactive compounds due to their antioxidant activity to protect organisms against harmful effects of oxygen radicals. A special case is the legumes that are also rich source of proteins, dietary fiber, micronutrients, and bioactive phytochemicals. Many legume species are still an irreplaceable source of dietary proteins for humans, especially in the mainly vegetarian diets of developing countries. Incorporation of leguminous seeds into the human diet can offer protective effects against chronic diseases because they contain a number of bioactive substances including phenolics that can increase protein digestibility and mineral bioavailability. However, technological processing and seed germination can impact the levels of natural endogenous antioxidants (e.g., phenolics, tocopherols; vitamin C) in leguminous seeds. Therefore, this chapter is a review about reports of antioxidant properties and their relationship with their total phenolic content of the most commonly consumed legumes. Researches about changes in the content of natural antioxidants during technological processing are included as well as some clinical reports concerning to the health benefits offered by legumes of higher consumption.

**Keywords:** legumes, beans, soybeans, phenolics compounds, antioxidants

## 1. Introduction

Food legume crops are considered vital for agriculture in developing countries for their nutritional value in which rely both the producers and consumers. Food legumes are an important source of protein and minerals, complementing the diet when combined with cereals. In agronomical terms, legumes crops serve as rotation crops with cereals, increasing the amount of nitrogen and also reducing soil pathogens [1]. Added to this, extensive research has proven that fruits and vegetables contribute significantly to the body supply of bioactive compounds due to their antioxidant activity attributed to the phenolic compounds that are known to protect organisms against harmful effects of oxygen radicals. A special case is legumes that are also rich source of proteins, dietary fiber, micronutrients, and bioactive phytochemicals. Experimental, epidemiological, and clinical studies show correlations between the consumption of food legumes and decreasing incidence of several diseases, such as cancer, cardiovascular diseases, obesity, and diabetes [2–4]. The antioxidant capacity [5] and the antimutagenic [6, 7], apoptosis-related [8], and antiproliferative effects of legumes are associated with the presence of phenolic compounds [9, 10].

The antioxidant capacity of legumes is within a wide range, because it depends on the biological variety of the plant and its origin. On the other hand, technological processing and seed germination can impact the levels of natural endogenous antioxidants (e.g., phenolics, tocopherols; vitamin C) in leguminous seeds. However, food processing not only improves flavor and palatability of foods but also increases the bioavailability of nutrients, by inactivating antinutritional factors, growth inhibitors, and hemagglutinins [11]. Legumes must be cooked—typically by boiling process—before consumption, because it changes the chemical composition and physical characteristics, such as flavor, color, and biological active components. To accelerate the cooking process, legumes should be soaked prior to boiling. Other cooking alternatives include pressure boiling and steaming. Moreover, a high-quality product might be obtained using high-pressure cooking technology [12].

This chapter is a review about some relevant reports about the antioxidant properties and their relationship with their total phenolic content of the most commonly consumed legumes, as well as some researches about changes in the content of natural antioxidants during technological processing and some clinical reports concerning to the health benefits offered by legumes of higher consumption.

## 2. Legumes description

Legumes belong to the family Leguminosae, one of the most important families in Dicotyledons, including around 700 genera and 20,000 species [13]. Leguminosae or Fabaceae is the third most populous family of flowering plants (behind Asteraceae and Orchidaceae) and include important pasture, grain, and agro-forestry species [14].

Legume is a plant characterized by edible seeds, borne in pods that often open along two seams, by pea-shaped flowers, and by compound stipulate leaves [15]. These include alfalfa, clover,

lupins, green beans and peas, peanuts, soybeans, dry beans, broad beans, dry peas, chickpeas, and lentils, and those of them represent an important component of the human diet in several areas of the world, where they complement the lack of proteins from cereals, roots, and tubers [16]. Legumes, such as lentils, chickpeas, and beans, have been cultivated for millennia all around the world; therefore, they have played a big role in many traditional cuisines of Asia, Central and South America, Middle East, and the Mediterranean, along with cereals (e.g., maize, barley, wheat, and rice) [17]. Although legume research is mostly dedicated to dry seeds [18], legumes are also consumed in salads as green vegetables (i.e., fresh pods, leaves, and seedlings); contain natural antioxidants; and are generally recognized as safe (GRAS) for human consumption. Proteins contained in legumes can counteract the oxidative effects of free radicals in biomolecules (e.g., DNA, lipids, and other proteins). In general, legumes are considered to be a better source of nutrients than cereals, because of their low glycemic indexes and fat (2–5%) and high amount of proteins, fibers, and carbohydrates (55–60%), which might be the reason why legumes were considered beneficial in traditional medicine [19, 20].

## 2.1. Antioxidant properties of higher consumption legumes

Antioxidants in legumes, such as flavonoids, phenolic acids, lignans, and tannins, are abundant in the seed coats [21, 22]. These phenolic compounds have a number of favorable physiological properties that are beneficial against chronic diseases. Antioxidants are naturally present in leguminous seeds; however, technological processing and seed germination can diminish their presence [11]. Antioxidant activities and phenolic compounds in raw legumes have been reported in several earlier communications. The following section describes some relevant studies on the antioxidant properties of the most common legumes (common beans, soybean, lima bean, lentils, peanut, peas, and chickpea).

### 2.1.1. Common bean (*Phaseolus vulgaris* L.)

Common bean (*P. vulgaris* L.), a member of the Leguminosae family, is a grain consumed in considerable quantities around the world. It is a plant native to America, specifically to the Andean and Mesoamerican regions. Common beans are a good source of protein (16–33%), some vitamins, minerals, and complex carbohydrates [23]. They also contain secondary metabolites such as tannins, anthocyanins, phenolic compounds, and fiber. There is evidence that these compounds, identified like to phytochemicals, play an important role in prevention and treatment of certain diseases. For example, the lower incidence of colon cancer registered in Latin-American countries as compared with other countries is partially due to the higher consumption of common bean [24].

Some of the main phenolic compounds found in various types of beans and their physiological properties are the following [25–29]: flavonoids (i.e., caffeic, *p*-coumaric, ferulic, and sinapic esters) present in a methanolic black-bean seed coat extract are thought to diminish liver injury in animal models, as well as colon, breast, and prostate cancer proliferation. Polyphenols present in a hot water pinto-bean hull extract increase bone metabolism in mice. Tannins, also present in black beans, hamper cancer cell proliferation. Anthocyanins are found in black beans

(i.e., delphinidin, petunidin, and malvidin), pinto beans (i.e., kaempferol), and pink beans (i.e., quercetin and kaempferol), although their physiological effects have not been reported.

Moreover, peptides released after enzymatic hydrolysis also act as antioxidants because the phenolic, indole, and imidazole groups contained in their amino acids function as proton donors that stabilize free radicals [30]. Particularly, total hydrolysates (TH) or peptides derived after enzymatic hydrolysis and fractioning procedures from protein leguminous such as chickpea, soybean, pea, lentil, mung bean, and common beans have demonstrated an important antioxidant and angiotensin-I converting enzyme (ACE) [31]. The ACE is a key element in the rennin angiotensin system (RAS) responsible for the control of blood pressure. Recently, [32] reported that the protein hydrolysates and peptidic fractions obtained from different varieties of common beans (*P. vulgaris*) have several biological activities, such as the antioxidant, antimicrobial (inhibit the growth of *Shigella dysenteriae*), and antihypertensive activities (*in vitro* and *in vivo*).

A comparative study of protein profile and potential bioactive peptides of improved common bean cultivars grown in Mexico and Brazil was carried out, and the major identified proteins were phaseolin, lectin, and protease and  $\alpha$ -amylase inhibitors, and abundant peptides were identified by HPLCMS/MS with molecular masses ranging from 300 to 1500 Da [33]. Peptides from common bean proteins presented potential biological activities related to control of hypertension and type-2 diabetes. As inflammatory reactions often include the formation of tissue-damaging oxidation products, compounds with high antioxidant activity may inhibit inflammation. Results by Oomah et al. [34] with bean hulls support previous studies in which antioxidant and anti-inflammatory activities of extracts are associated with polyphenols capable of inhibiting COX and LOX [34–36]. Animal models of cellular activity also provided evidence for chemopreventive effects of black bean hull extracts.

There are also some studies relating the beneficial effect of whole bean and reduction of chronic diseases related to inflammation such as colon cancer [37] and diabetes mellitus [38]. The antioxidant capacity of protein hydrolysates and the effects on the markers of inflammation in lipopolysaccharide (LPS-induced RAW 264.7) macrophages were evaluated in common bean (*P. vulgaris* L.) varieties, Negro 8025 and Pinto Durango [23]. They concluded that hydrolysates from the common bean could be used to combat inflammatory and oxidative-associated diseases.

Furthermore, the influence of thermal processing (canning and open pot) of common beans (*P. vulgaris* L.) varieties Black 8025 (N), Bayo Victoria (BV), Pinto Durango (PD), and Pinto Saltillo (PS) in their chemical composition, and their antioxidant and anti-inflammatory activities in a human intestinal cell model, was evaluated [39]. They concluded that the effect of cooking on bioactive compounds from common beans is cultivar dependent, being more quantitative than qualitative as a consequence of the release of bonded phenolics. Although the thermal processing is partially degrading some phenolics, at the same time it is releasing other bonded polyphenols. Cooked beans have shown good antioxidant properties as the raw materials, and in some cases, even better than the raw beans.

### 2.1.2. Soybean (*Glycine max* (L.) Merr. *Fabaceae*)

Soybeans are one of the most produced commodities worldwide and are among the most important crops for human and animal consumption; however, only four countries (USA, Brazil, Argentina, and China) are responsible for providing nearly 90% of soybean seeds worldwide [40]. Soybean seeds [*Glycine max* (L.) Merr. *Fabaceae*] contain a significant amount of protein (~40%) and oil (~20%). The antioxidants of soybeans are represented by isoflavones, tocopherols, ascorbic acid, and some other compounds [41, 42].

When soybeans are processed into different foods, the particular antioxidants content of the produced foods may change depending on the processing procedure [43] and storage conditions [44] and differ from the initial antioxidant content in the soybeans [45].

This species is a widely used crop because of its valuable beneficial health effects on several chronic diseases, including the prevention of cancer (including breast, colon, and prostate cancers), osteoporosis, cardiovascular disease, and multiple conditions ameliorated by antioxidants [46–48]. On the other hand, for a practical application in the food industry, antioxidants should be first extracted. The efficiency of the extraction process affects the antioxidant capacity of the extract [49]. Studies on the extraction of the antioxidant activity in unfermented soybeans and vine have reported a variation of the total phenolic concentration when different solvents were used, which is due to differences in their polarities [50]. Limited information is available regarding the extraction of antioxidant compounds in fermented soybeans. However, significant higher concentration of phenolics was obtained after fermentation when compared to unfermented soybeans [51, 52]. Until now, a regular extraction protocol has not been established because of the complex nature of the soybeans and their wide range of antioxidants. Also, other factors such as the temperature and the nature of solvent might react unpredictably and alter the extraction efficiency [53].

It is well established that the insoluble-bound phenolic compounds have high antioxidant and antiradical activities when compared with those of soluble and free phenolic compounds [54]. Soybean has high contents of the soluble phenolics, such as isoflavone and anthocyanin, in comparison with other phytochemicals. It has been reported in several studies the phenolic compounds and antioxidant activity of soybean. Among soybeans containing various seed coat colors, black soybeans showed strong antioxidant properties using the  $\alpha,\alpha$ -diphenyl- $\beta$ -picryl hydrazyl (DPPH), ferric-reducing antioxidant power (FRAP), and oxygen radical absorbance capacity (ORAC) methods [48]. Brown and black soybeans contain highly polymeric seed procyanidins and anthocyanins [55]. Furthermore, black soy beans were observed higher radical scavenging activities than those of green and yellow soy beans [56].

The measured distribution of antioxidant capacity in black soybeans depends on the assay technique: DPPH and FRAP methods show that the seed coat contributes to 90% of the entire antioxidant activity of the soybean; conversely, the ORAC method shows that the seed coat and dehulled part of the soybean contribute equally to the antioxidant capacity [12]. These results, although contradicting, are helpful for the creation of effective treatments.

The antioxidant activity and contents of various polyphenol classes in the seeds of 20 soybean hybrids were evaluated [57]. They found a positive linear correlation between the antioxidant



capacity and the total contents of phenolics, tannins, and proanthocyanidins. Extracts of hybrids were found to have the highest antioxidant activity because they contained large amounts of polyphenols. On the other hand, single-cross hybrids are deficient in tannins and are thus suggested as livestock fodder. These studies sought to demonstrate that polyphenols are significant component of soybean seeds.

#### 2.1.3. Lima beans (*Phaseolus lunatus* L.)

Lima beans have been domesticated in the United States and present two major gene pools: (1) the Mesoamerican one, with small seeds and wild types distributed in Mexico, Central America, and eastern part of the Andes. (2) The Andean pool with large seeds and wild types distributed predominantly in the Western part of the Andes, in Ecuador, and Northern Peru [58, 59]. Embrapa Genetic Resources and Biotechnology has an Active Gene bank of *P. lunatus* L., with approximately 330 accessions collected predominantly in Brazil [60]. Lima bean (*P. lunatus* L. Walp) belongs to the family Fabaceae and genus of *Phaseolus*. *P. lunatus* seeds powder is largely prescribed in traditional medicine for promoting suppuration on application to small cuts on tumors and abscesses [61]. The medicinal values of plants lie in their phytochemical components, which produce definite physiological results on the human body [62]. Polyphenolics compounds appear to play a significant role as antioxidants in the protective effect of plant-derived foods and medicine [63] and have become the focus of current nutritional and therapeutic interest in recent years.

Lima bean (*P. lunatus*) seeds coat was evaluated for its chemical composition, phytochemical constituents, and *in vitro* antioxidant activity. Epidemiological studies have demonstrated that there is a positive relationship between intake of antioxidant rich diets and lower incidence of degenerative diseases caused by reactive oxygen species (ROS) and reactive nitrogen species (RNS) [64], such as cancer, heart disease, inflammation, arthritis, and immune system decline [65]. Recently, more attention has been focused on the potential utilization of agricultural by-products in the development of new functional ingredients for food enrichment to provide an economic alternative for industries and sustainability of the environment [66]. Often, agricultural by-products are sources of bioactive compounds with functional properties, such as fiber and phenolics that have antioxidative defense system against some degenerative diseases or disorders in biological system. The proportion of coat (>10% by weight) of the lima bean seeds is quite high and as such constitutes a kind of environmental nuisance. There is a dearth of information on the phytochemical constituents and antioxidant capacity of *P. lunatus* seeds coat. In this study, it is reported that *P. lunatus* seeds coat were found to be a good source of phytochemicals and radical scavenging activities. Therefore, it becomes important to promote maximal use of agro by-products such as seeds coat in the development of new functional ingredients for food and environmental sustainability [67].

#### 2.1.4. Lentils (*Lens culinaris* Medik.)

Lentils, like many other legumes, have been cultivated in societies all around the world for centuries [68]. Lentils come in a variety of presentations: canned, dry-packaged, whole, split, or processed into flour. Lentils are commonly used in vegetarian cuisine, as well as in salads,

stew, and soups because they contain substantial amounts of protein, fibers, minerals, and antioxidants [69]. Lentils are not only an excellent source of macronutrients such as protein, fatty acids, fibers, and carbohydrates, but also contain phytochemicals that can be categorized into phenolic acids, flavanols, flavonols, soy saponins, phytic acid, and condensed tannins [70, 71].

Epidemiological studies suggest that lentils confer protection against chronic diseases through a multitude of biological activities including antioxidant, anticancer, angiotensin I-converting enzyme inhibition, reducing blood lipid, and reducing the risk of cardiovascular diseases [72]. The phenolic compounds have potential health benefits in people with coronary heart disease, type II diabetes, and obesity [73, 74]. Lentils are often recommended in Western diets because of their beneficial effects; they are considered to be good sources of nutrients and calories. There is information about polyphenols and their properties in lentil, but scarce knowledge is available regarding to the effect of processing on the phenolic compounds. The effects of cooking, soaking, and industrial dehydration treatments on the phenolic profile and antioxidant properties of the *Pardina* lentil have been studied using HPLC-PAD and HPLC-MS (ESI) methods. The principal phenolic compounds found in raw and processed lentils were ( $\beta$ )-catechin, 3-glucoside, procyanidin trimer, and procyanidin B2 [75]. Other important findings regarding the processing of lentils were that dehydration and ordinary cooking did not reduce phenolic compounds. Moreover, antioxidant activity in raw lentil flours is reduced after processing; however, it is still of relevance to consider processed lentil flour in the human diet for its phenolic compounds and antioxidant activity [70].

With the current upsurge of interest about the efficiency and function of natural antioxidants in food and biological systems, the testing of antioxidant activity has received much attention [76]. Thus, there are some researches reporting the effect of germination on nutritional value of legumes. Other studies have evaluated the effect of bioprocess on lentil's (*L. culinaris*) phenolics composition and antioxidant activity in order to improve the content of antioxidant compounds, and obtain processed lentil flours with added value that could be used by the food industry as functional ingredients [76, 77].

Lentils contain different concentrations of the hydroxybenzoic phenolic compounds, protocatechuic, vanillic acid, aldehyde *p*-hydroxybenzoic, *trans*-ferulic acid, and *trans-p*-coumaric acid [78]. The amount of phenolic compounds increased significantly ( $p \leq 0.05$ ) after germination. Germination process causes various changes in the phenolic compounds and modifies their antioxidant activity; therefore, lentil sprout flour or extract can be used as a source of natural antioxidants in functional foods. Germination modifies the quantity and quality of phenolic compounds of legumes [78]. Further research is needed to elucidate the composition of the seed extract for identification and level of bioactive compounds. The impact of food processing methods as well as physiological processes like digestion on the stability of these phytochemicals and their antioxidant activity needs to be established in order to use lentils as natural therapeutic food supplement [79].



### 2.1.5. Peanut (*Arachis hypogaea* L.)

The peanut cultivar plays an important role in the economy of several countries (China, India, USA, Netherlands, UK, Germany, Russia, and Spain). Peanut (*A. hypogaea* L.) is one of the major oilseed crops of the world. It is also an important source of food protein in many countries. They can be eaten raw, boiled, or roasted, are used in recipes, made into flour, oil, and peanut butter. Raw peanuts are also free of sodium and *trans*-fats, and have high-protein content (about 25%). Recently, peanuts have gained much attention as functional food [80].

A chemical analysis, total phenolic content, and antioxidant capacity were carried out of two varieties of peanuts [81]. Phenolic compounds such as resveratrol, catechin, epicatechin, and quercetin were identified in both samples. The obtained values for resveratrol in all samples were higher than those reported in literature. The antioxidant capacity of raw skin and roasted peanuts Virginia variety was slightly higher in the defatted samples. The same occurred with the samples of the Spanish variety. The raw and roasted conditions also showed slight differences that are mainly attributed to differences in extraction methods. It is important to bear in mind that the peanut skin represents a potential source of natural antioxidants suitable for use as food additives, as reported by [82]. The antioxidant capacity of these samples depends on the mining methods employed, type of sample (skin or seed), origin, and storage time, among others [81].

The phenolic compounds in the outer layers of plants such as peel, shell, and hull are present in high concentration to protect inner materials such as the cotyledon. A number of phenolic acids, however, are covalently bound with insoluble polymers. Heat treatment may liberate the low-molecular antioxidant compounds from the repeating subunits of high-molecular-weight polymers [83]. Despite being rich in phenolics and antioxidants [84], peanut seed coat is considered to be a by-product by the peanut processing industry.

Peanut skins and hulls also contain natural phenolic compounds, which can be extracted for commercialization in the food industry. The main ones are proanthocyanidins [85], caffeic acid, chlorogenic acid, ferulic acid, coumaric acid, catechins, procyanidins and stilbene (resveratrol) [84], and ethyl protocatechuate [86]. Thirty to forty peaks were detected from the three peanut skin types at 280 nm. Similar findings were observed in a study by Yu et al. [87], which showed numerous peaks at 280 nm.

High total phenolic content in peanut hulls of varied maturity is associated with a high antioxidant activity and with an important role in the stability of lipid oxidation. In this study, both the ethanol extract and EP (ethyl protocatechuate) reacted as scavengers against  $\alpha, \alpha$ -diphenyl- $\beta$ -picryl hydrazyl (DPPH) and hydroxyl radicals. In addition, the ethanol extract was found to act as a metal-binder. Using 70% ethanol, Nepote et al. [88] were able to extract 118 mg of phenolic antioxidants per gram of dried peanut skins.

Consuming peanuts on daily basis reduces the risks of weight gain [89], cardiovascular diseases [90], Alzheimer's disease, and cancer [91]. Recent research has showed that peanuts contain antioxidants, phenolics, and other phytochemicals including flavonoids, proanthocyanidins [92], anthocyanins [93], and resveratrol [94]. These phytochemicals are found to have

protective function against cancer, coronary heart diseases, degenerative nerve disease, Alzheimer's disease, and viral/fungal infections.

#### 2.1.6. Peas (*Fabaceae*)

Peas are cultivated during the cool season. Peas grow in vines that can reach 9 ft long, although, modern vines are only 2 ft long. Peas consist of a hollow stem [95], two large leaf-like stipules, one to several pairs of oval leaflets and terminal tendrils. Modern vines with *afila* (semileafless) leaflets might have additional tendrils [96].

Pea (*Pisum sativum* L.) has been extensively used in early hybridization studies, and it was the model organism of choice for Mendel's discovery of the laws of inheritance, making pea part of the foundation of modern genetics [97]. Ripe seeds are round, smooth or wrinkled, and can be green, yellow, beige, brown, red-orange, blue-red, dark violet to almost black, or spotted (NRCS Plant Materials Center, Pullman, Washington).

Sugar snap peas, snow peas, and garden peas are the most common varieties of this legume crop. The younger the peas are, the sweeter and tenderer they will be. Garden peas were developed into snap peas to create easily snapped pods, which can also be eaten because they have low-fiber content. Snow peas are harvested before the peas develop. When the peas "shell," they can be eaten raw or cooked. It is important to cook peas with the smallest amount of water possible in order to conserve most of the nutrients.

The antioxidant and antiradical properties of phenolic compounds of extract of pea seeds were studied [98]. An extract of seeds of pea was prepared using 80% (v/v) acetone. Six fractions (I–VI) were separated from the crude extract on a column Sephadex LH-20 using methanol as the mobile phase. The antioxidant activity of fractions of peas was very strong as compared with that of butylated hydroxyanisole (BHA). Absorption maxima from UV spectra showed that flavonoids, and not phenolic acids, were the main phenolic compounds in separated fractions. The strong antiradical activity of tannins separated from the crude extract should be emphasized. Vanillic, caffeic, *p*-coumaric, ferulic and sinapic acids, quercetin, kaempferol, procyanidin B2, and procyanidin B3 were found as active phenolic compounds in the investigated material [99].

Cooking peas might not necessarily cause the loss of nutrients, depending on the process: microwave cooking causes no significant nutrient loss, whereas boiling causes a 39% loss of ascorbate, but only a minor loss of water- and lipid-soluble antioxidant activities; overcooking leads to a loss of 61% of water-soluble antioxidant activities and 34% of ascorbate [100]. On the other hand, frozen vegetables have similar activities to fresh vegetables, whereas canned or jarred vegetables do not. As expected from previous publications, antioxidant activity is lost on storage of fresh vegetables after harvest; however, appropriate cooking methods retain total antioxidant activity, although overcooking may result in substantial losses.

Most research of legume antioxidant activity has studied fresh samples [101]. However, legumes are often consumed after being stored, processed, and cooked in a variety of ways, which may impact the levels of nutrients. Ascorbate loss has been already documented [102].

The effects of limited hydrolysis on functional properties, as well as on protein composition of laboratory-prepared pea protein isolates, were investigated by [103]. The results showed a slight positive correlation of 0.74 between solubility and emulsifying activity index (EAI) and a negative correlation of  $-0.60$  between solubility and foam stability, and also between foam stability and EAI of  $-0.77$ . A detected improvement in the functional properties was due to a partial hydrolysis of insoluble protein complexes.

#### 2.1.7. Chickpea (*Cicer arietinum* L.)

Chickpea also called “garbanzo bean” or “Bengal gram,” is an Old-World pulse and one of the seven Neolithic founder crops in the Fertile Crescent of the Near East [1]. It is an annual grain legume (pulse crop) that is extensively cultivated for human consumption. Chickpea is cultivated throughout the world, including the Mediterranean basin, the Near East, Central and South Asia, East Africa, South and North America, and Australia [9]. It is the second-most important pulse crop in the world (after dry bean), covering 15% (10.2 million ha) of the area dedicated to pulse cultivation and accounting for 14% (7.9 million tons) of pulse production worldwide [104].

Other countries with a significant production of chickpea include Pakistan, Turkey, Australia, Myanmar, Ethiopia, Iran, Mexico, Canada, and the USA. India is the largest chickpea-producing country with an average production of 6.38 million metric tons during 2006–2009, accounting for 66% of global chickpea production [104]. The chickpea is a component of the diet in the semiarid tropics as it is a rich source of both protein and carbohydrates, which constitute 80% of the total mass of dry seed [105, 106]; it is free of cholesterol and is a source of dietary fiber (DF), vitamins, minerals, folate,  $\beta$ -carotene, and health-promoting fatty acids [107]. There is little scientific evidence regarding the beneficial effect on the health of the components in chickpea. However, it is reported that the consumption of chickpea reduced the risk of some chronic diseases [106].

Several studies have shown that legumes generally contain significant amounts of polyphenols, flavonoids, and antioxidant activity that vary widely depending on its type [12, 74]. For example, chickpea color contains a lot of polyphenols and flavonoids with high antioxidant activity but the common chickpea beige seeds have low levels of these compounds with a low antioxidant activity [12, 74]. However, both of them can be used for studies of functional foods.

On the other hand, both chickpea and other legumes should be cooked before consumption to improve taste and palatability and to increase their nutritional bioavailability by inactivation of antinutritional factors [9, 11]. However, it has been reported that although the chickpea color containing high levels of phenolic material exhibiting high levels of antioxidant activity, processes such as soaking, cooking, and steaming significantly affect the total phenols content (TPC) and antioxidant activities of all tested types of chickpeas [9]. In this study, the authors suggested that the use of soaking at room temperature for 22 h in combination with steaming for 1 h is the best way to retain the polyphenols, flavonoids, and the antioxidant activity of colored chickpea.

### 3. Effect of processing on legumes properties

Antioxidant activities and phenolic compounds in raw legumes have been reported in several earlier communications [43, 99]. As already mentioned, legumes must be cooked before consumption. However, there are few reports about how processing methods affect the health promoting phenolics and antioxidant activities. Food processing not only improves flavor and palatability of foods but also increases the bioavailability of nutrients, by inactivating antinutritional factors, growth inhibitors, and hemagglutinins [11]. The cooking causes a number of changes in chemical composition and physical characteristics of dry legumes, which are usually cooked by a boiling process before use. Pressure boiling and steaming can also be used. High-pressure processing technology may provide high quality of food products (flavor, color, biological active components) [12].

Soaking, boiling, and steaming processes significantly affect the total phenolic contents and antioxidant activities in legumes as green pea, yellow pea, chickpea, and lentil. The changes depended on the type of legume and processing conditions. Steaming process causes smaller losses in TPC, antioxidant activities, and solid mass than the boiling process. Hence, steaming is recommended for legumes preparation in domestic and industrial processes, for preserving antioxidant components and decreasing cooking time. The changes in the overall antioxidant properties of processed food could be attributed to the synergistic combinations or counteracting of several types of factors, such as oxidative reaction, leaching of water-soluble antioxidant compositions, formation or breakdown of antioxidant compositions, and solid losses during processing [12].

#### 3.1. Food technologies applied on legumes

Food technologies are increasingly oriented to providing health and wellness to consumers. The average per capita food consumption has increased 17% over the past 30 years and still, the world face lack of sufficient food for individuals and family problems and malnutrition on one side and overweight and obesity on the other. Moreover, there is increasing evidence that the nutrients in a food may not be fully available for absorption in the stomach depending, for example, on processing conditions and the presence of other components in the diet. In many cases, processed foods show improved bioavailability of nutrients when compared with fresh or raw that only go through mastication before being ingested. Impact of technology on nutrition will change as we learn more about the fate of the components after ingestion [108].

Seeds of legumes can be divided into two types: those where energy is stored as fat as in the case of soybean, lupin, and others, and where energy is deposited in the form of starch, such as beans, peas, lentils, chickpeas, and others. Interest in legumes is based on the nutritional value they provide. Seeds of peas are low in fat and high in protein of excellent quality (about 25% crude protein), starch (35–45%) as well as dietary fiber and a variety of micronutrients as minerals and bioactive compounds with claimed anticancer effects, such as vitamins and antioxidants [109]. On the other hand, legumes are also reported to have antinutritional factors that reduce their nutritious value.

### 3.2. Effects of processing on nutrients

Processes applied to legumes can be classified into three groups: the preparation of raw materials involving washing, cutting, or chopping; preservation operations, such as sterilization, drying, freezing, or freeze-drying; and transformation processes all of which aim to increase the shelf life of the foodstuff. Postharvest practices for most seeds and beans are threshing, hulling, or removal of pods as well as drying or dehydration, after which the product can be stored. During drying and storage, it is important to prevent mold contamination and aflatoxins. After postharvest operations carried out on the farm, the products go to markets that lead the consumer or agribusiness. In addition to primary products, oilseeds and legumes produce considerable quantity of by-products or such as shells, fibers, pods, which can be used as fuel or for animal feed. FAO has programs to help farmers in postharvest activities by means of the creation and diffusion of technology, training in quality management and marketing, and usage of materials [104].

Processes such as peeling and heat-related ones such as cooking, drying, autoclaving, extrusion, and others may positively impact quality by reducing antinutritional compounds and improving digestibility of protein and starch so that changes induced by heat need to be investigated from a biochemical point of view being necessary to specially study effects on proteins and carbohydrates [11]. It is important to study the processing effects of enzymes (proteases, amylases,  $\alpha$ -galactosidases) that can facilitate digestion of various nutrients as well as usage of other enzymes such as tannases, which could allow for the degradation of certain antinutritional factors. For example, it has been recommended to add fitase to prevent phytic acid antinutritional properties. Addition of fitase to flours of legumes aids decreasing antinutritional factors and iron bioavailability [110, 111].

Pea, chickpea, and lentil whole flours have great potential in different processes due to their functional properties. High content of water, good oil absorption and gelation, emulsifying, and foaming capacities make these flours useful in bakery products, soups, dairy products, gluten-free foods, and other new products. Studies on functional and processing characteristics of whole legumes and fractions as well their emerging food and nutraceutical applications must be carried out [112].

In addition, a combination of the above-mentioned techniques and the effect of additives (such as citric acid, sodium bicarbonate) on the nutritional quality of the legumes has been studied. A comparison of various techniques allows for the selection of the better processes enabling improvement in the nutritional value with a minimum loss of nutrients and reduction in antinutrients. Among all the processing techniques, germination is recommended to improve the nutritional value of legumes by increasing bioavailability of minerals, vitamins, digestibility and decrease in antinutrients during germination. Cooking treatments (ordinary cooking, pressure-cooking, and microwave cooking) in addition to improving digestibility importantly decrease content of antinutrients [113]. Germination of peas increases digestibility of proteins, crude fiber, and decrement in phytic acid and polyphenols. Various authors have reported that soaking and cooking of peas, chick peas, and lentils reduce the content of estaquiose, raffinose, and  $\alpha$ -galactoside (flatulence inducer compound). It has been demonstrated that boiling, autoclaving, and microwaving cooking affect the composition, presence



of antinutritional compounds, and flatulence factors as well as nutritional quality of chickpeas [113].

Microwave cooking caused slight losses in minerals, whereas boiling and autoclaving caused significant losses. Cooking improved the *in vitro* protein digestibility and protein efficiency ratio of lentils. It is clear that cooking lentils by microwave saves time and help to retain their nutritional value. The effects of microwave cooking and other traditional cooking methods such as boiling and autoclaving on nutritional composition and antinutritional factors of lentils showed that by using conventional cooking, the concentrations of lysine, tryptophan, total aromatic, and sulfur-containing amino acids decreased. The losses in minerals in lentils cooked by microwaving were smaller than those cooked by boiling and autoclaving [114]. Microwave cooking may be recommended for legume preparation, for enhancing nutritional quality as, for example, leading to a better retention of B-vitamins and minerals, reduction in the level of antinutritional factors, and to increase digestibility of proteins and reduction of cooking times. Soaking and cooking processes cause minimum vitamin loss and may be conducted by using 0.1% citric acid solution or in water and subsequent microwaving cooking [115]. Effects of soaking and cooking on the chemical composition and digestibility of winged beans have been investigated. These authors found that there was an increase in protein content, total carbohydrates, and digestibility in samples subjected to soaking and cooking. Wang et al. [116] combined effects on the nutrients of soaking, water, and steam blanching, further oligosaccharides and trypsin inhibitor activity (TIA) in cowpea and demonstrated that the combination of soaking and steam blanching had less effect on losses of nutrients. Besides, steam blanching caused a higher reduction in TIA than water blanching. However, water blanching reduced more oligosaccharides in cowpea. Soaking does not affect starch gelatinization during water blanching but the effect of soaking on the gelatinization of starch was significant when in combination with steam blanching. The losses in minerals in lentils cooked by microwaving were smaller than those cooked by boiling and autoclaving. Based on these results, microwave cooking is recommended for lentil preparation, not only for improving nutritional quality, but also for reducing cooking timer [116]. Fermentation, on the other hand, considerably reduces phytic acid given the inactivation of endogenous fitase and microbial growth [117].

#### 4. Conclusions

The epidemiological evidence indicated that the consumption of dietary antioxidant such as legume seed proteins, provides protective effects for several chronic diseases such as cardiovascular diseases, cancer, obesity, diabetes, and hypercholesterolemia. As vegetables are a major source of antioxidants it is desirable assess their antioxidant activity and compare different processing and preparation methods. Legumes are important components of human diet and are subjected to various processing method that can affect composition and nutritional value. The mild heat treatments are recommended over heat-intensive ones for the processing of legumes; in order to avoid deactivation of enzymes and lose of nutrients, which can also achieve by using germination, microwaving, and fermentation. Also addition of enzymes, such

as phytases, helps preserving bioavailability of iron. Fermentation and germination are highly recommended in order to obtain enhanced functionality. The information presented in this chapter shows the potential nutritional importance of the legumes and its role on improved nutrition and human health.

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## Author details

Ma. del Socorro López-Cortez\*, Patricia Rosales-Martínez, Sofía Arellano-Cárdenas and Maribel Cornejo-Mazón

\*Address all correspondence to: socolc@prodigy.net.mx

National School of Biological Sciences-IPN. Department of Biophysics. Prol. de Carpio y Plan de Ayala, Col. Casco de Sto. Tomás, México D.F.

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